Time-of-Travel Study, Batten Kill From 0.6 Mile East of Vermont-New York Border to Clarks Mills, New York

By
Harold L. Shindel
U.S. Geological Survey

REPORT OF INVESTIGATION
RI-12

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New York State Department of Environmental Conservation

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Prepared by
UNITED STATES DEPARTMENT OF THE INTERIOR
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SYMBOLS

C	numerical constant
$C_{(obs)}$	peak concentration observed, in micrograms per liter
$C_{(adj)}$	peak concentration adjusted for dye losses, in micrograms per liter
C_{max}	expected maximum concentration at an intake, in micrograms per liter
$C_{(Rel)}$	peak concentration, adjusted for dye loss and weight of dye injected, in micrograms per liter
C_u	peak concentration adjusted for dye loss, weight of dye injected, and discharge of receiving waters, in micrograms per liter
Kx	dispersion coefficient, in square feet per second
n	factorial constant
PR	percentage of dye recovered
Q	discharge, in cubic feet per second
$\Sigma_{ci}\Delta_t$	area under the dye-dispersion curve, in micrograms per liter-hours
S	soluble contaminant spill, in pounds
σ_t^2	variance of the dye-dispersion curve, in hours squared
$\Delta\sigma_t^2/\Delta X$	change of variance of the dye-dispersion curve with distance between the injection and sampling site, in seconds squared per foot
T_e	estimated time of travel of the peak, used for dye injection, in hours
TT	time of travel, in hours and minutes
$\bar{U}$	average velocity of the centroid, in feet per second
V_d	volume of dye injected, in ounces
ΔX	length of the subreach

TIME-OF-TRAVEL STUDY, BATTEN KILL

FROM 0.6 MILE EAST OF VERMONT-NEW YORK BORDER TO CLARKS MILLS, NEW YORK

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SUMMARY

Time of travel was determined for the 30.8-mile reach of Batten Kill between BM 543 bridge, 0.6 mile east of the New York-Vermont border, and Clarks Mills, New York. Rhodamine B and Rhodamine WT dyes were used to determine the time of travel. Cumulative peak time of travel for the peak concentration flow of about 46-percent duration was 47 hours and for a flow of approximately 89-percent duration was 101 hours. Relationships between peak, centroid, leading, and trailing-edge times of travel and discharge through the subreaches are shown graphically.

Time-of-travel data for each subreach as well as cumulative time graphs for the entire reach for different discharges are given. Dye dispersion and peak-analysis information are also given.

INTRODUCTION

This report presents the results of a time-of-travel study from June 11 to August 1, 1968, of Batten Kill between the site of BM 543 bridge, 0.6 mile east of the New York-Vermont border, and Clarks Mills, New York. Traveltime represents the integrated effect of an infinite number of the stream's cross sections. During this time, physical and biological mechanisms reduce the effects of pollutants. Using the basic time-of-travel data, sanitary engineers can evaluate a stream's ability to cleanse itself and can recommend treatment facilities if needed. The data are useful in water-sampling programs because their use makes possible the sampling of the same slug of water from head-water to mouth by adjusting a sampling schedule to correspond to the stream's velocity. Traveltime data also provide a base for action in case of accidental spills of a soluble contaminant. The "Dye-dispersion" section of the report shows some supplemental uses of basic time-of-travel data.

Fieldwork was done by the U.S. Geological Survey under the general supervision of Garald G. Parker, former district chief, in cooperation with the New York State Department of Environmental Conservation. The report was compiled under the supervision of Robert J. Dingman, district chief.

The time needed by a stream to move its accompanying soluble contaminants from point to point is called the time of travel between those points. Time of travel may be measured by using floats, analyzing average stream

velocities at selected cross sections, and tracking various chemicals. A variation of the chemical-tracking method, which uses fluorescent-dye tracers and seems to provide the most reliable results, was used. Briefly stated, the method requires that a fluorescent dye be dumped into a stream and that periodic samples then be taken at some downstream point until the slug of dye has passed. Therefore, the time necessary for the peak concentration of the dye to pass from the dump point to the sampling point is the the time of travel between those points. The fluorescent-dye method is explained more fully in the "Operations" section of the report.

The following references have been found useful in the preparation of this report: Fair and Geyer, 1963; G. K. Turner Associates, 1963; Mack, Pauszek and Crippen, 1964; Sayre and Chang, 1968; Shindel, 1969a and b; and Wilson, 1967.

DESCRIPTION OF REACH

Batten Kill flows south from the Green Mountains of Vermont to Arlington, Vermont, from where it flows in a westerly direction to the Hudson River in New York.

This study deals with the reach from BM 543 bridge, a small bridge 0.6 mile east of the New York-Vermont Border, to Clarks Mills, New York (fig. 1). The slope of the 31-mile reach is approximately 13.8 feet per mile. Velocities are relatively swift in the upper part of the reach, where there are no dams or obstructions. Velocity in the lower part of the reach is affected by dams built mostly by various paper companies. The most upstream dam, which slows the flow somewhat, is at East Greenwich, New York. The next two dams are at Battenville and Center Falls (Blandy Paper); these two dams affect stream velocities little if at all. Dams at Standard Packaging (Greenwich), at Stephen and Thomson (slightly west of Middle Falls), and at Clarks Mills all provide enough storage to slow the water considerably. Of all the dams in the reach, the one at Clarks Mills is the largest, provides the most storage, and causes the lowest velocities.

Batten Kill is gaged in two places--at Arlington, Vermont, and at Battenville, New York. The gage at Battenville was operative during the field study but was discontinued September 30, 1968.

In the 0.5 mile reach between Clarks Mills and the mouth, velocities are swift, and the approximate traveltime of the peak concentration ranges from 0.5 hour for the higher discharge (46-percent duration) to 0.75 hour for the lower discharge (89-percent duration).

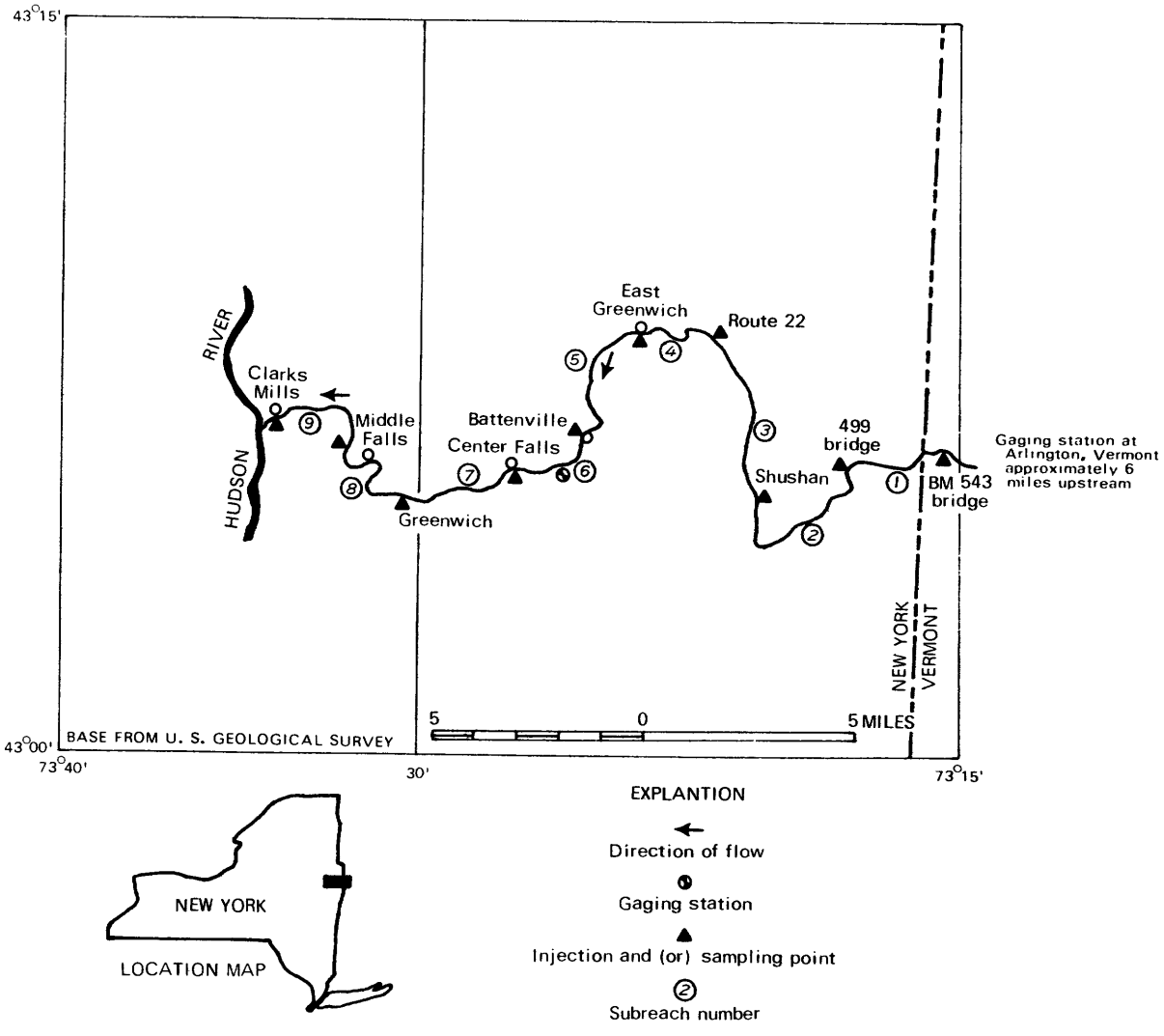


Figure 1.--Location of reach, subreaches, and gaging stations on Batten Kill.

OPERATIONS

Prior to actual field operations, field and map reconnaissances were made to determine prospective subreaches, lengths of subreaches, and division of responsibility for sampling; lengths of subreaches were determined from the largest scale U.S. Geological Survey map available. A description of each subreach, map(s) on which it is plotted (7½-minute and 15-minute U.S. Geological Survey topographic quadrangles), mileage, and location of the sampling point are listed in table 1.

The field procedure consisted of injecting the dye at the upstream site and taking samples at selected time intervals at the downstream sampling site for each subreach. Although many dye tracers are available for this type of study, Rhodamine B 40-percent and Rhodamine WT 20-percent tracers were chosen for use in Batten Kill. These tracers were chosen for their high detectability, economy, ease of handling and injection, and nontoxicity in the concentrations used. After doing the Batten Kill study,

Table 1.--Data on the study reaches

Subreach		Map reference (topographic quadrangle)	Length of subreach (miles)	Location of sampling point
Number	Location			
1	BM 543 bridge (Vt.) to 499 bridge	Shushan (7½')	3.4	Bridge
2	499 bridge to Shushan	do.	5.1	Do.
3	Shushan to Route 22	Shushan-Salem (7½')	4.4	Do.
4	Route 22 to East Greenwich	Salem-Cossayuna (7½')	2.2	Do.
5	East Greenwich to Battenville[1]	Cossayuna-Cambridge (7½')	3.8	Do.
6	Battenville[1] to Center Falls (Blandy Paper)	Cambridge (7½')	2.2	Do.
7	Center Falls to Greenwich (Standard Packaging)	Cambridge-Schuylerville (15')	3.3	Wing wall
8	Greenwich to Middle Falls	Schuylerville (15')	3.3	Do.
9	Middle Falls to Clarks Mills[2]	do.	3.1	Bridge at Clarks Mills

[1] Standard Packaging, just upstream.

[2] Hollingsworth and Vols Paper Co.

the New York District of the U.S. Geological Survey discontinued the use of Rhodamine B but continued to use Rhodamine WT dye. Although WT is more costly, it is reported to have a higher recovery rate than Rhodamine B. This property of the dye is useful in dispersion studies. In this study, the remaining stocks of Rhodamine B were used in the upper subreaches. Rhodamine WT was used in the lower subreaches as an added precaution to avoid contamination to the various paper mills in the subreaches. The volume of dye injected insured that the peak concentration at the downstream site would be less than 10 µg/l (micrograms per liter), as required by the U.S. Geological Survey. The amount of dye to be injected was computed by the formula:

$$V_d = CQT_e, \text{ where}$$

V_d is the amount of dye injected, in ounces;
Q is the discharge, in cubic feet per second, at the sampling site;
T_e is the estimated time of travel, in hours; and
C is a constant.

To assure a downstream concentration of less than 10 µg/l, a target concentration of 2 µg/l was used. The final formula then became:

$V_d = 0.01Q\ T_e$ for the Rhodamine WT 20-percent dye, and
$V_d = 0.005Q\ T_e$ for Rhodamine B 40-percent dye.

After the samples were taken, they were analyzed in a Turner Model III fluorometer. The instrument is basically an optical bridge that uses a rotating prism to relate the fluorescence of a sample to a calibrated rear light path. The fluorometer is calibrated with prepared standards. At low concentrations, the dial reading varies linearly with the amount of fluorescence. The fluorometer may be used with either a flow-through door or with individual sample cuvettes. An individual sampling technique was used in the study. Samples were analyzed in the laboratory and the concentration was noted. The time interval between injection and arrival of peak concentration of dye was considered the peak time of travel; the interval to the first trace of dye was considered the leading-edge time of travel; and the interval to the last trace of dye was considered the trailing-edge time of travel. Centroid and dye-dispersion data were computed from the time-concentration curve. An example of these curves is shown as figure 2.

Discharge was obtained from the gage records at the stations: Batten Kill at Arlington, Vermont, and Batten Kill at Battenville, New York. For intermediate subreaches, discharges were interpolated on the basis of drainage areas. Mean daily discharges for these stations are published in the annual U.S. Geological Survey reports, "Water Resources Data for New York, Part 1, Surface Water Records." An abstract of the descriptions for the stations is given in table 2.

Locations of the gages and the injection and sampling sites are shown in figure 1.

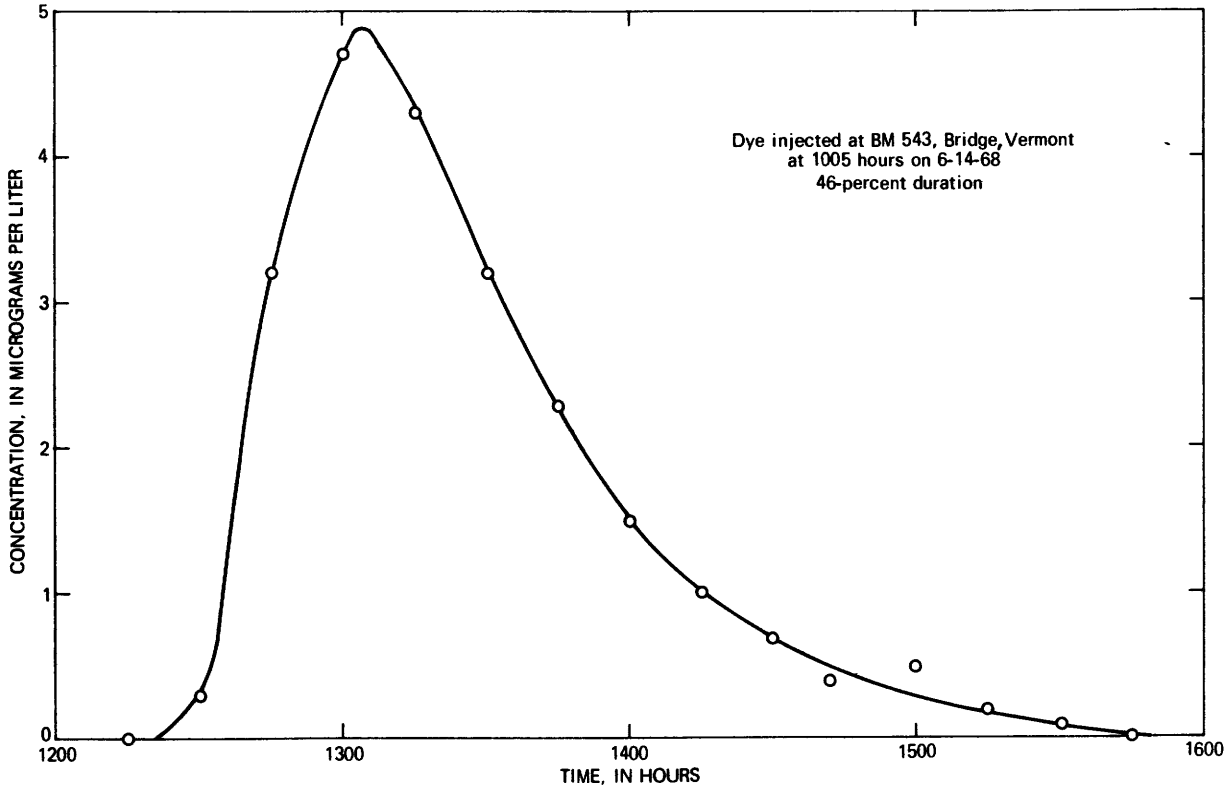


Figure 2.--Time variation and dispersion of dye concentration, at 499 bridge, Batten Kill, June 14, 1968. (A typical curve.)

Table 2.--Gaging-station descriptions

1-3290. Batten Kill at Arlington, Vt.

Location.--Lat 43°04'38", long 73°09'26", on left bank 5 feet upstream from bridge on Highway 313 at Arlington, Bennington County, and 0.9 mile downstream from Warm Brook.

Drainage area.--152 sq mi.

Gage.--Digital water-stage recorder.

1-3295. Batten Kill at Battenville, N.Y.

Location.--Lat 43°06'05", long 73°25'55", on left bank 1 mile southwest of Battenville, Washington County, and 1.2 miles upstream from Trout Brook.

Drainage area.--394 sq mi.

Gage.--Digital water-stage recorder.

ANALYSIS

Time of Travel

To establish valid discharge versus traveltime relationships, two studies were made to measure the times of travel at different discharges. The results of the measurements are shown in table 3. In the reach from Stephen and Thomson dam to Clarks Mills, it was not possible to find the centroid and the trailing edge at low flow because of (1) the poor definition of the curve after the peak and (2) the concurrent arrival of an upstream dye injection at the sampling site. The graphical relationships, based on table 3, and extended slightly, are shown in figures 3 to 11.

Figure 12 shows cumulative times of travel for leading and trailing edges, peak, and centroid for the highest and the lowest discharges studied.

To find any time of travel for a rate of discharge not studied, refer to the discharge at the lower end of the subreach in figures 3 to 11. Read the traveltime for the subreach. Addition of the traveltimes for each of the subreaches will give the desired time of travel. A word of caution is in order, however. Traveltimes computed from long extensions of the discharge-time curves may be erroneous.

Table 3.--Time-of-travel data

Subreach number	Length of subreach (miles)	Date 1968	Discharge (cubic feet per second)	Time of travel: Leading edge (hour: minute)	Time of travel: Peak (hour: minute)	Velocity peak (feet per second)	Time-of-travel centroid (hour:minute)	Velocity centroid (feet per second)	Time-of-travel trailing edge (hour:minute)	Date 1968	Discharge (cubic feet per second)	Time of travel: Leading edge (hour: minute)	Time of travel: Peak (hour: minute)	Velocity peak (feet per second)	Time-of-travel centroid (hour:minute)	Velocity centroid (feet per second)	Time-of-travel trailing edge (hour:minute)
1	3.4	6/14	300	2:15	3:00	1.66	3:13	1.55	5:40	8/ 1	100	4:30	5:45	0.87	6:24	0.78	10:00
2	5.1	6/14	320	3:40	4:25	1.69	4:50	1.55	6:40	8/ 1	105	7:10	9:10	.81	9:53	.76	14:10
3	4.4	6/14	330	3:05	4:10	1.55	4:34	1.42	8:05	7/31	110	6:00	8:30	.76	8:48	.73	13:00
4	2.2	6/14	460	2:15	2:40	1.22	3:13	1.00	5:35	7/31	150	5:00	6:45	.48	7:26	.43	11:45
5	3.8	6/13	470	2:20	2:45	2.03	3:08	1.78	5:05	7/31	156	4:30	5:30	1.01	6:07	.91	9:30
6	2.2	6/13	470	1:40	2:00	1.61	2:08	1.51	2:55	7/31	160	3:15	4:30	.72	5:08	.63	7:45
7	3.3	6/13	475	5:05	6:35	.74	6:43	.72	8:45	7/30-31	165	13:15	18:00	.27	19:49	.24	28:15
8	3.3	6/13	510	3:55	4:45	1.02	5:10	.94	7:05	7/30-31	175	8:10	10:40	.45	14:01	.35	26:40
9	3.1	6/18-19	420	12:50	17:00	.27	18:35	.24	27:50	7/29-8/1	185	25:00	32:00	.14	--	--	--

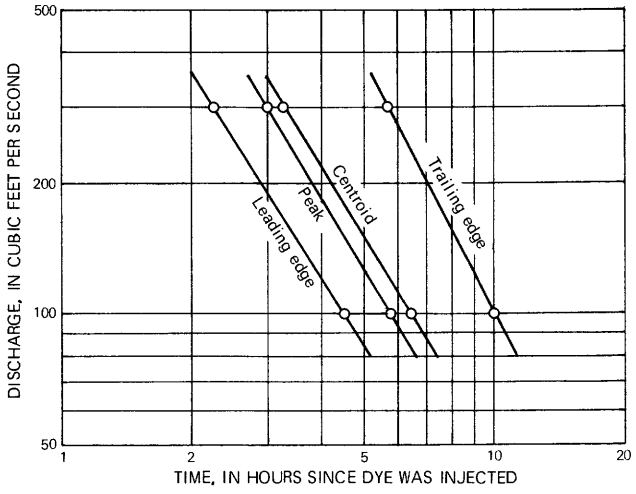


Figure 3.--Relation of discharge to leading edge, peak, centroid, and trailing edge times of travel: BM 543 bridge to 499 bridge.

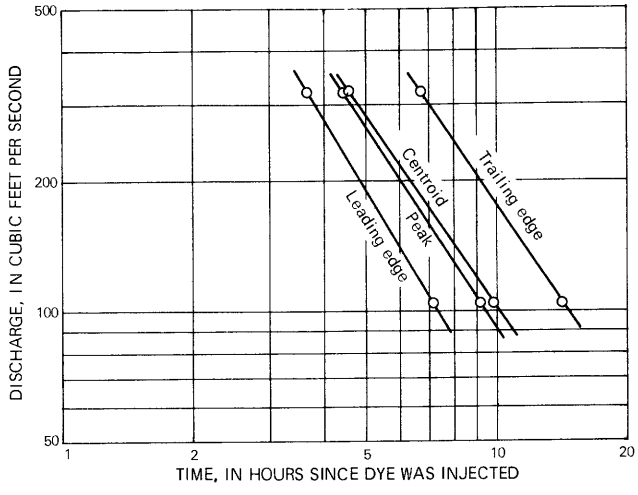


Figure 4.--Relation of discharge to leading edge, peak, centroid, and trailing edge times of travel: 499 bridge to Shushan.

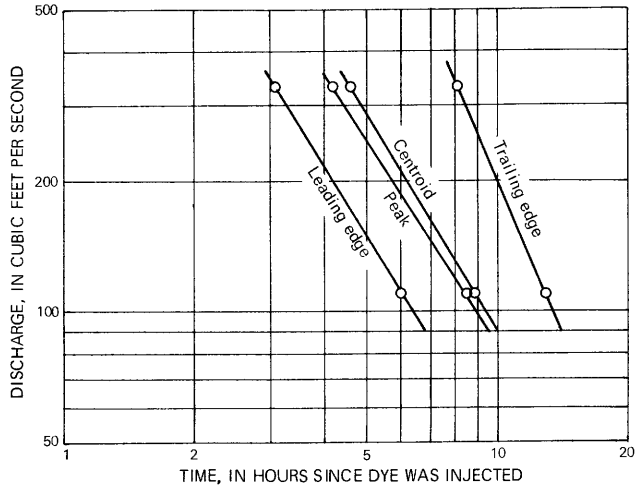


Figure 5.--Relation of discharge to leading edge, peak, centroid, and trailing edge times of travel: Shushan to Route 22.

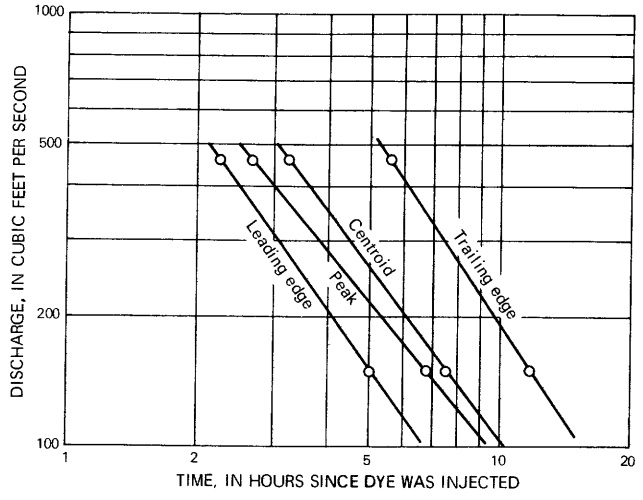


Figure 6.--Relation of discharge to leading edge, peak, centroid, and trailing edge times of travel: Route 22 to East Greenwich.

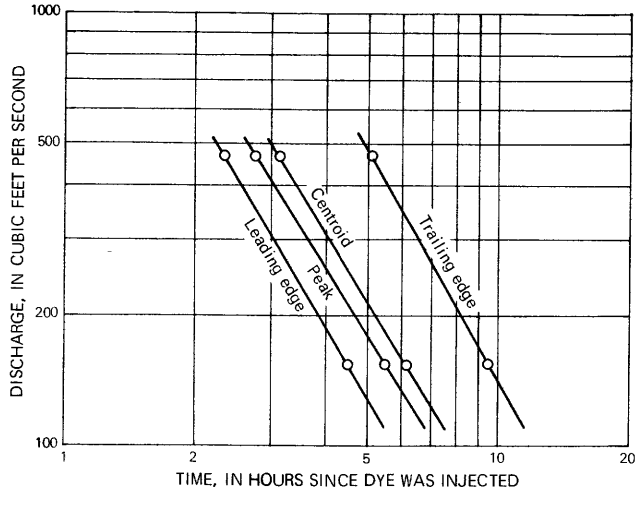


Figure 7.--Relation of discharge to leading edge, peak, centroid, and trailing edge times of travel: East Greenwich to Battenville.

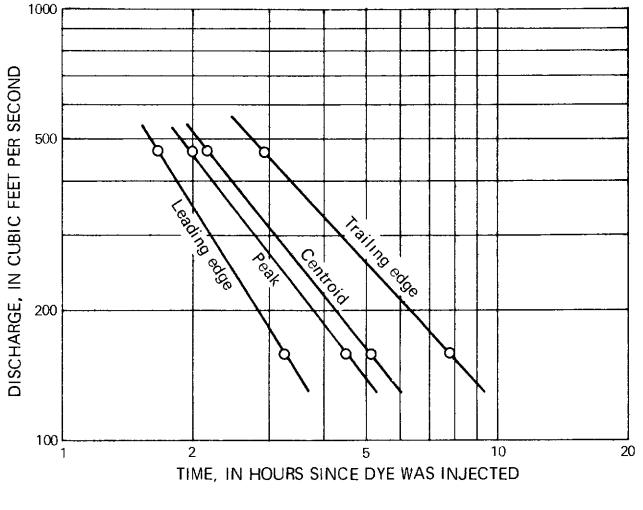


Figure 8.--Relation of discharge to leading edge, peak, centroid, and trailing edge times of travel: Battenville to Center Falls.

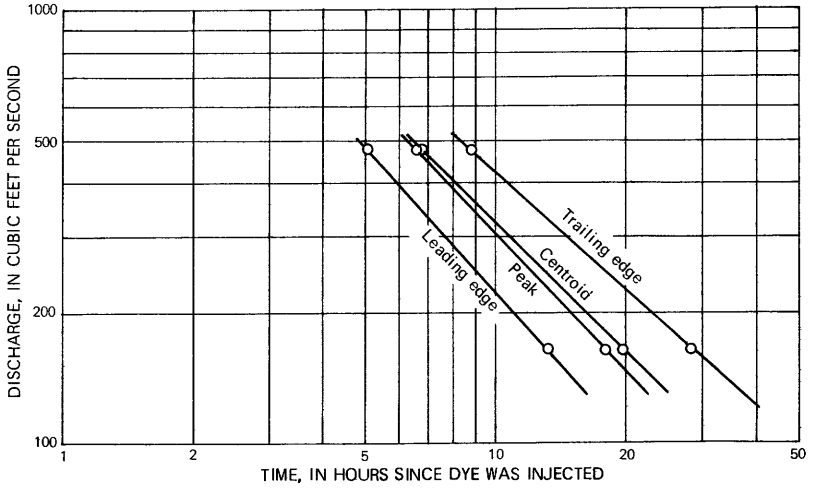


Figure 9.--Relation of discharge to leading edge, peak, centroid, and trailing edge times of travel: Center Falls to Greenwich.

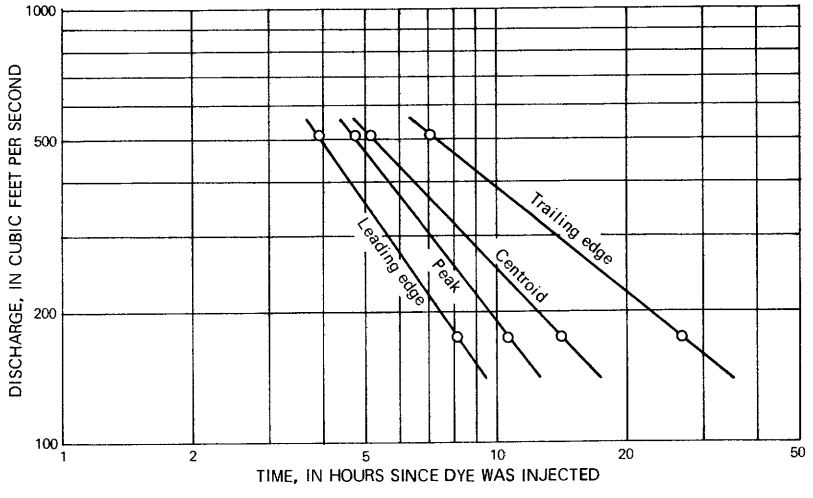


Figure 10.--Relation of discharge to leading edge, peak, centroid, and trailing edge times of travel: Greenwich to Middle Falls.

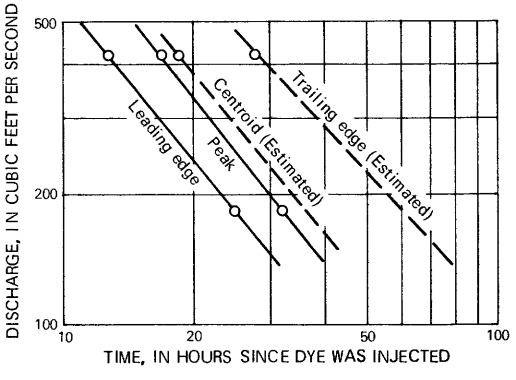


Figure 11.--Relation of discharge to leading edge, peak, centroid, and trailing edge times of travel: Middle Falls to Clarks Mills.

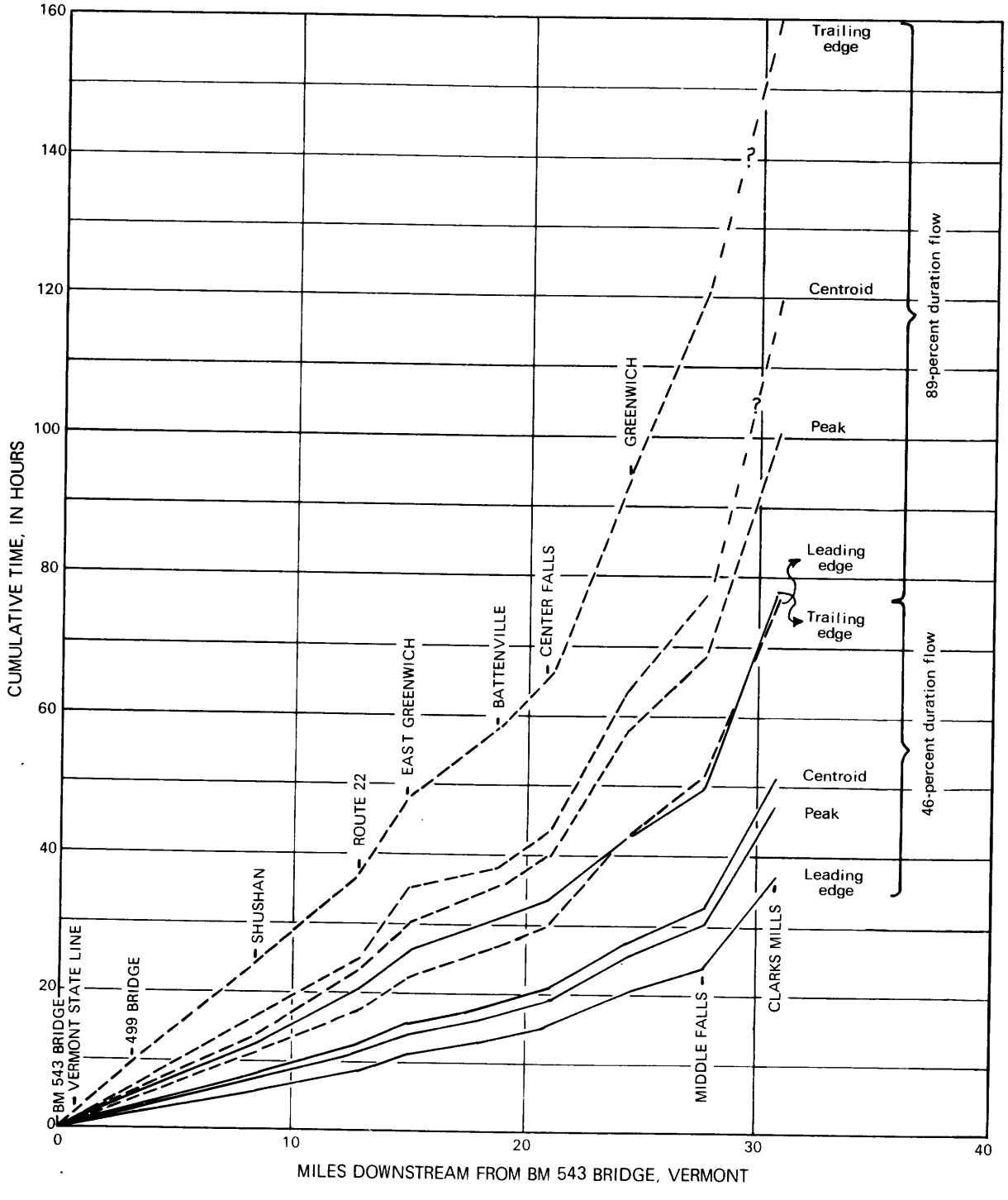


Figure 12.--Cumulative times of travel for Batten Kill from BM 543 bridge in Vermont to Clarks Mills, New York, for 46-percent and 89-percent duration flows.

Dye Dispersion

Knowledge of diluting and spreading characteristics of a stream is important in evaluating the effect of a suddenly injected contaminant into a stream. These characteristics vary with stream channel and flow and can be evaluated from the dye-dispersion curve. The data from the curves generated by the Batten Kill time-of-travel study have been used with the computational procedures outlined by F. A. Kilpatrick (written commun., 1970), and the results are given in table 4 and figure 13.

Use of the unit-peak relationship, figure 13, is shown in the following example:

1. Assume that 1,000 pounds of soluble contaminant were spilled at Center Falls.

2. Assume there is an intake at Middle Falls. What will be the maximum concentration of the contaminant at Middle Falls?

3. Assume that the flow at Greenwich is 300 cfs (cubic feet per second) and the flow at Middle Falls is 320 cfs.

4. From the discharge-time relationships, figures 9 and 10, the peak time of travel is found to be 10.0 and 6.8 hours, respectively. The cumulative peak time of travel is 16.8 hours.

5. From the unit-peak relationship curve, figure 13, the unit-peak concentration for a time of travel of 16.8 hours is 780 micrograms per liter.

6. The unit-peak concentration is then converted to the expected concentration by the formula:

$$C_{max} = C_u \times \frac{S}{Q} \quad \text{where}$$

C_{max} is the expected maximum concentration at the intake, in micrograms per liter;
C_u is the unit peak, in micrograms per liter;
S is the soluble contaminant spill, in pounds; and
Q is the discharge, in cubic feet per second, at the intake.
In this example: $C_{max} = 780 \times \frac{1,000}{320} = 2,440$ µg/l or 2.4 mg/l.

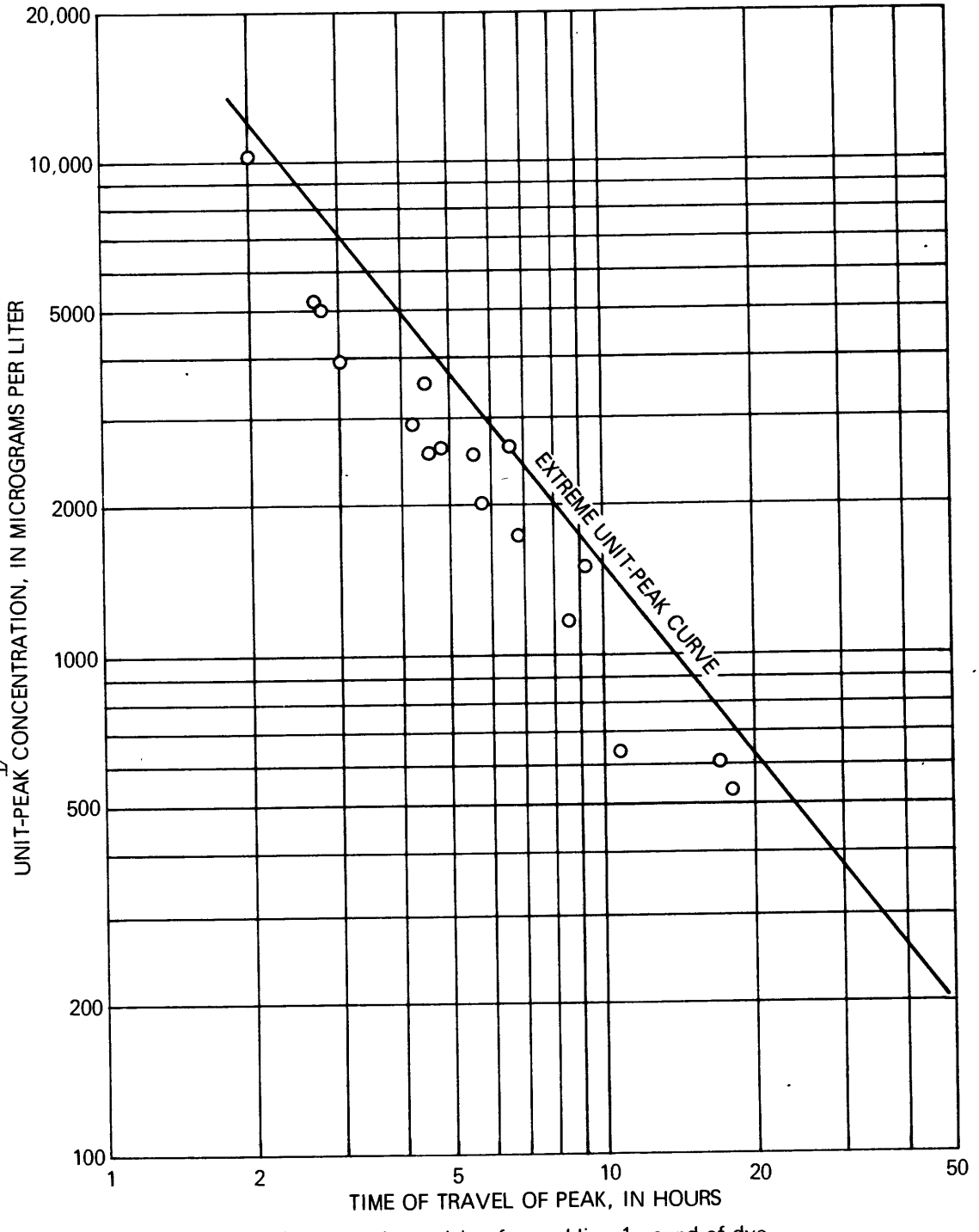
The sanitary engineer must, at this time, decide whether the 2.4 mg/l (milligrams per liter) contaminant can be handled or whether the intakes must be shut down until the contaminant passes. If the intakes must be shut down, figures 9 and 10 can be used to determine when the leading edge of the contaminant will reach the intake and when the channel will be clear.

In the "Percent of dye recovered" column of table 4, there are three readings of over 100 percent. These higher readings are probably attributable to mixing of the dye across the channel, the injection of dye that was highly concentrated because of the evaporation of the solvent in which it was dissolved, or a combination thereof.

Table 4.--Dye-dispersion data

Reach	Run number	Date 1968	Length ΔX (miles)	Area under dispersion curve $\Sigma c_i \Delta t$ (micrograms per liter-hours)	Time-of-travel centroid (hours)	Velocity centroid $\bar{U}$ (feet per second)	Variance of dispersion curve σ_t^2 (hours^2)	Change in variance with distance $\Delta\sigma_t^2/\Delta X$ (seconds^2 per foot)	Dispersion coefficient K_x (feet^2 per second)	Dye injected amount-type (ounces)	Discharge (cubic feet per second)	Percent of dye recovered	Peak concentrations (micrograms per liter) Observed	Adjusted	Relative	Unit
1	1	6/14	3.4	5.550	3.22	1.55	0.337	243.3	453.0	16 B	300	87.3	4.9	5.6	13.0	3,912
	2	8/ 1		13.175	6.40	.78	.994	717.6	170.3	16 B	100	69.1	6.0	8.7	20.2	2,018
2	1	6/14	5.1	6.075	4.84	1.55	.290	139.6	259.9	18 B	320	90.6	4.9	5.4	11.2	3,574
	2	8/ 1		14.100	9.88	.76	1.630	784.5	172.2	18 B	105	69.0	4.8	7.0	14.4	1,508
3	1	6/14	4.4	6.575	4.56	1.42	.673	375.4	537.5	18 B	330	101	4.4	4.4	9.0	2,965
	2	7/31		20.300	8.80	.73	1.954	1,090	212.0	24 B	110	78.0	5.4	6.9	10.7	1,179
4	1	6/14	2.2	2.638	3.22	1.00	.379	422.9	211.4	9 B	460	113	3.1	2.7	11.3	5,207
	2	7/31		8.625	7.43	.43	1.525	1,701	67.6	12 B	150	90.4	3.4	3.8	11.6	1,746
5	1	6/13	3.8	.798	3.14	1.78	.120	77.5	218.6	8 WT	470	67.9	.9	1.3	10.7	5,019
	2	7/31		10.300	6.11	.91	.799	516.1	194.5	30 WT	156	77.5	5.9	7.6	16.3	2,549
6	1	6/13	2.2	.432	2.14	1.51	.050	55.8	96.0	4 WT	470	73.5	1.0	1.4	21.9	10,301
	2	7/31		6.375	5.14	.63	.692	772.1	96.5	16 WT	160	92.3	3.7	4.0	16.1	2,583
7	1	6/13	3.3	.680	6.72	.72	.498	370.4	69.1	8 WT	475	58.4	.4	.7	5.5	2,618
	2	7/30-31		8.290	19.82	.24	9.219	6,857	47.4	24 WT	165	82.5	1.0	1.2	3.3	537
8	1	6/13	3.3	.610	5.16	.94	.464	345.1	143.3	8 WT	510	56.3	.3	.6	5.1	2,626
	2	7/30-31		8.350	14.01	.35	13.638	10,144	217.5	16 WT	175	132	1.2	.9	3.7	640
9	1	6/18-19	3.1	9.440	18.59	.24	8.381	6,636	45.9	64 WT	420	89.7	1.3	1.4	1.5	613
	2	7/29-8/1		--	--	--	--	--	--	96 WT	185	--	1.0	--	--	--

B - Rhodamine B
WT - Rhodamine WT



1/ The unit peak is the peak resulting from adding 1 pound of dye to a discharge of 1 cubic foot per second and assuming there is no dye loss in the channel

Figure 13.--Unit-peak attenuation curve for Batten Kill.

DISCUSSION

A flow-duration curve is a means of describing the distribution of daily mean flows that have occurred and can be used to predict the distribution of flows that may occur. The curve is a plot of flow versus percentage of time that the flow was equalled or exceeded. A 90-percent flow would indicate a low flow, one that has been equalled or exceeded 90 percent of the time. Similarly, a 10-percent flow would indicate a high flow, one that had been equalled or exceeded only 10 percent of the time. In contamination studies, low-flow periods are the ones of greatest interest because during such periods the stream has less water to dilute the contaminant inflow. Generally, a 75-percent or higher duration flow indicates low-flow conditions. The only gaging station actually on the reach studied was Batten Kill at Battenville. Figure 14 shows the flow-duration curve for this station.

A generally satisfactory definition of the discharge versus time-of-travel curve usually can be obtained by measuring time of travel at three selected discharge rates. To define the low discharge end of the graph (the part most critical in contamination problems) one of the time-of-travel measurements should be made near the 95-percent or higher duration point.

During this study, only two measurements were made--at approximately 46-percent and 89-percent durations. The desired lower flow measurements (95- to 99-percent duration) were not possible because flow did not reach that point. It was decided to publish the results of the two measurements so that they may be available to those interested. If the opportunity arises for a measurement at the desired duration point, an addendum to this report giving the new data and revised discharge-time relationships (if necessary) will be published.

As the study now stands, a straight-line log discharge-time relationship of the form $TT = CQ^n$ exists as shown in figures 3 to 11. Although previous studies generally have found a slight deviation from this straight line, the $TT = CQ^n$ discharge-time graph can be considered a close approximation to the actual conditions until additional measurements can be made.

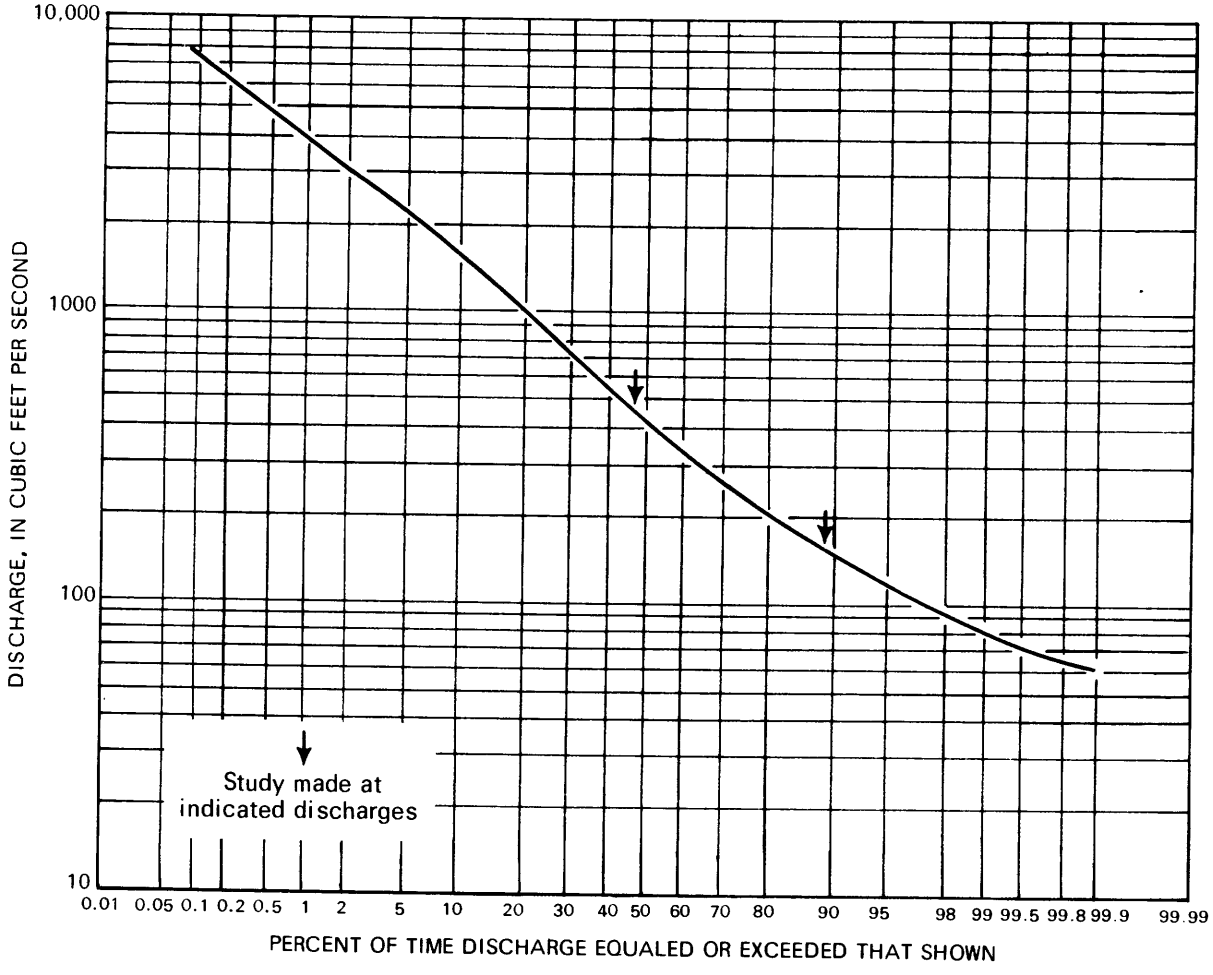

10,000
1000
100
10
DISCHARGE, IN CUBIC FEET PER SECOND
Study made at
indicated discharges
0.01 0.05 0.1 0.2 0.5 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.5 99.8 99.9 99.99
PERCENT OF TIME DISCHARGE EQUALED OR EXCEEDED THAT SHOWN

Figure 14.--Duration curve of daily mean flows for Batten Kill at Battenville, N.Y. (1923-62).

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